Remarks on possible local P-violation in heavy ion collisions

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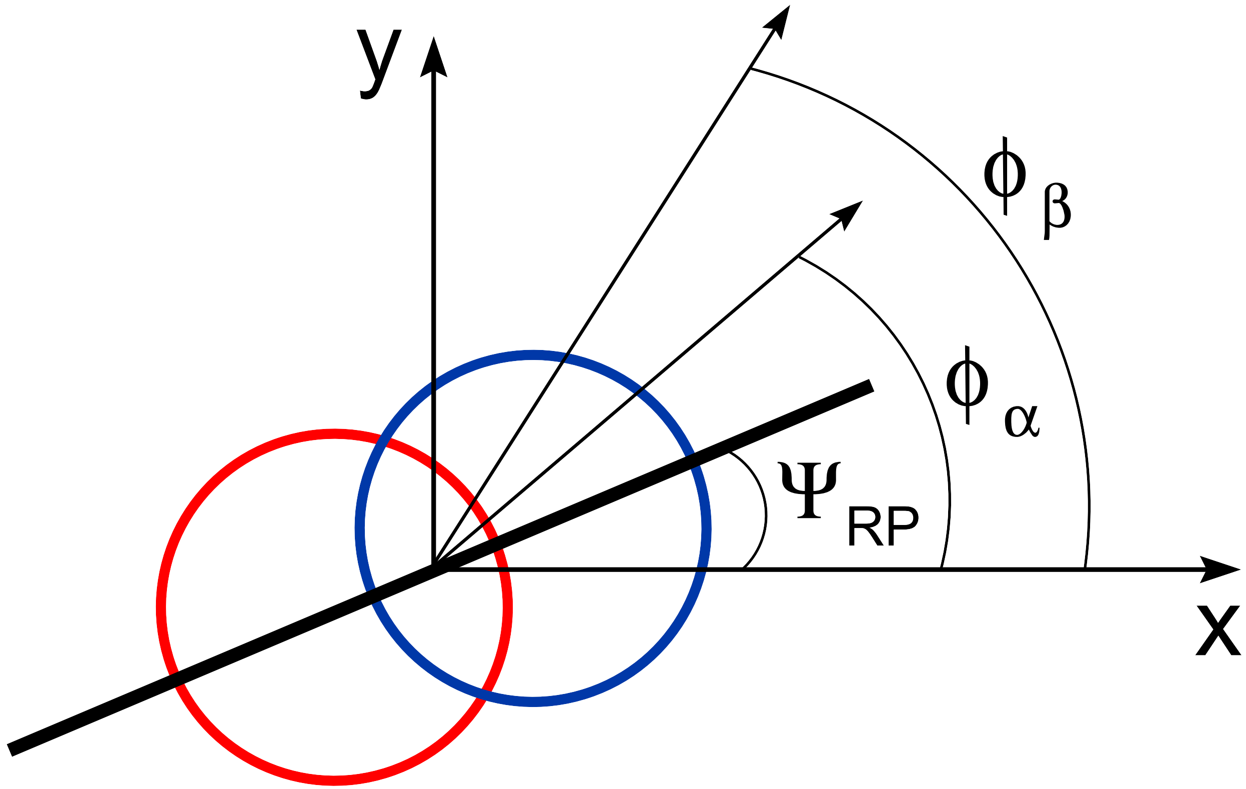
Outline

- introduction
- STAR data: integrated signal, p_t distribution
- v_2 contribution and Coulomb effect
- new dipole analysis
- conclusions

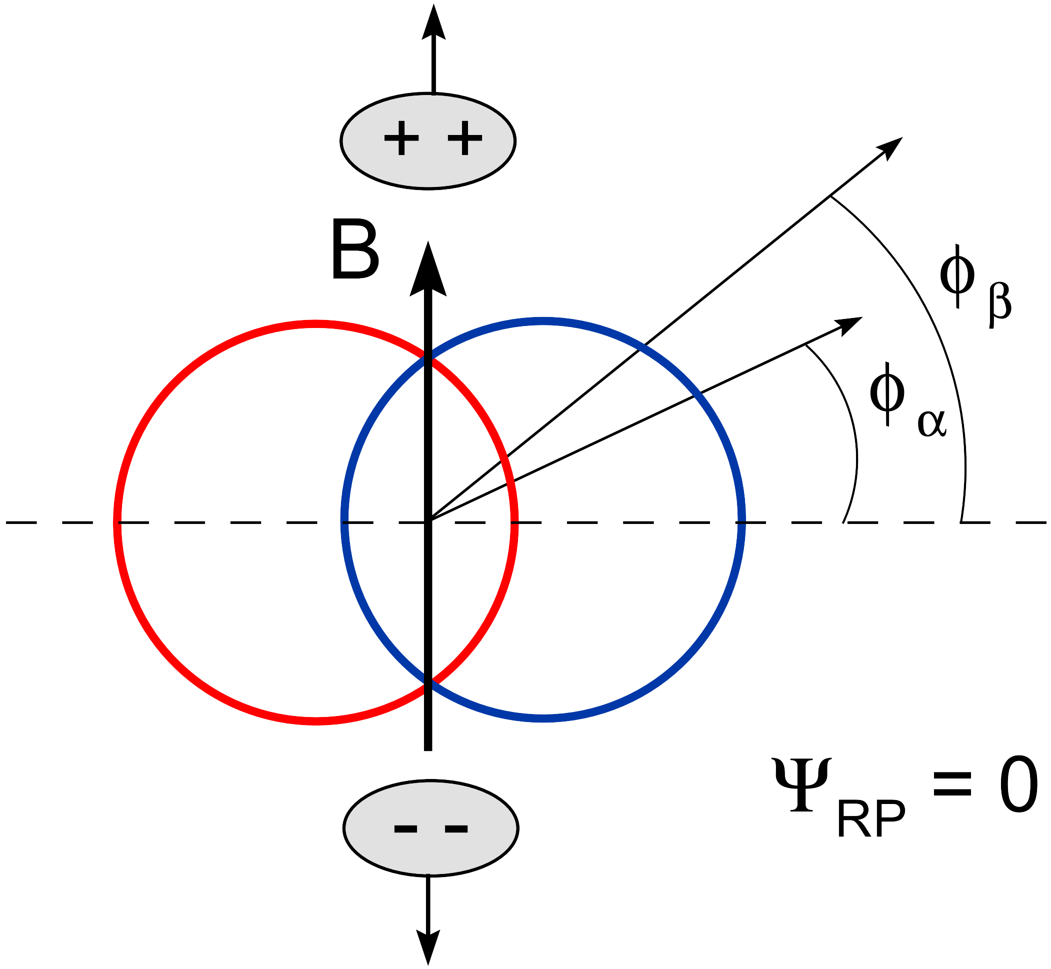
Introduction

Reaction plane



$\boxed{\textbf{We work in the frame where } \boldsymbol{\Psi_{RP} = 0}}$

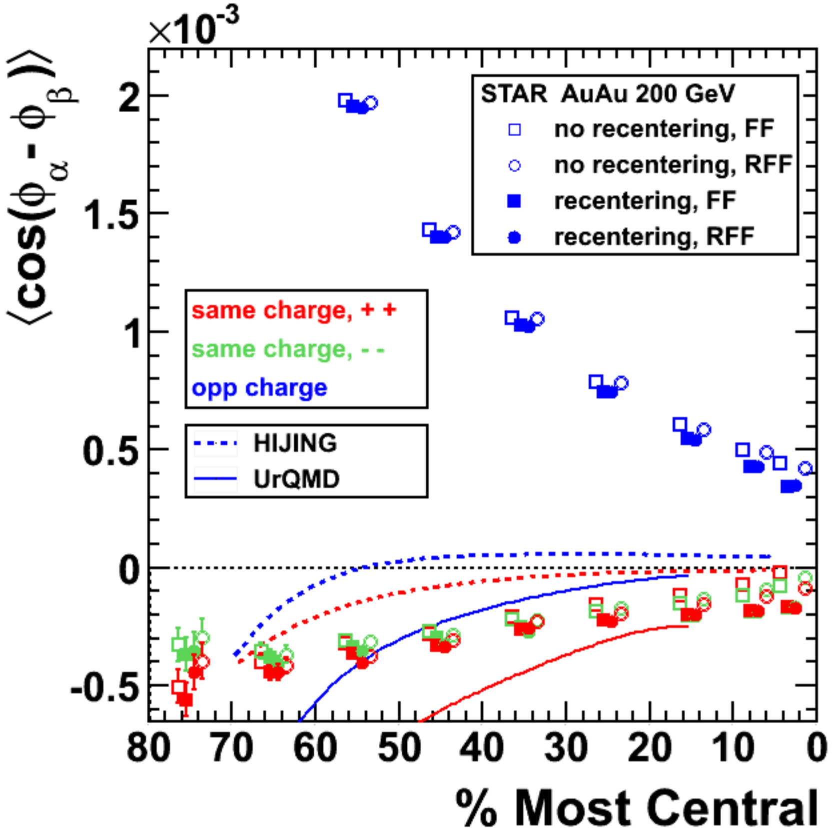
Chiral Magnetic Effect

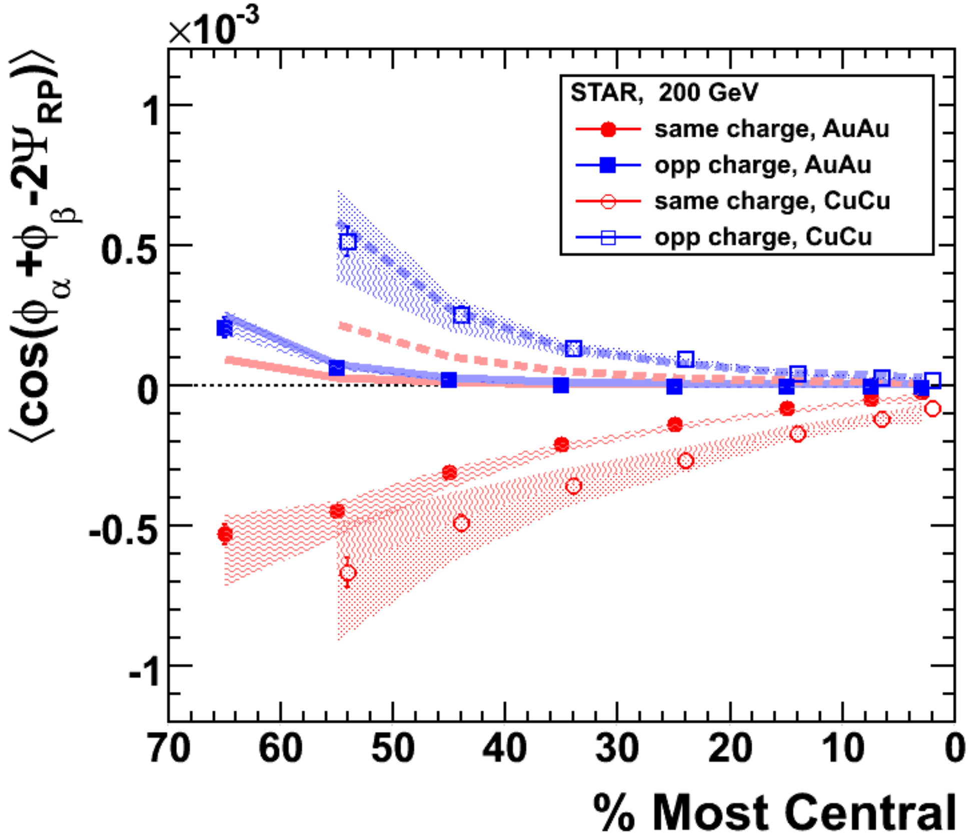


$$\boxed{\text{for same sign pairs: } \langle \sin(\phi_\alpha) \sin(\phi_\beta) \rangle > 0}$$

Integrated signal

STAR data





$$\boxed{\langle\cos(\phi_\alpha - \phi_\beta)\rangle_{same} \simeq \langle\cos(\phi_\alpha + \phi_\beta)\rangle_{same} < 0}$$

$$\langle\cos(\phi_\alpha - \phi_\beta)\rangle_{opposite} > 0; \quad \langle\cos(\phi_\alpha + \phi_\beta)\rangle_{opposite} \approx 0$$

from

$$\left\langle \cos(\phi_\alpha - \phi_\beta) \right\rangle = \left\langle \cos(\phi_\alpha)\cos(\phi_\beta) \right\rangle + \left\langle \sin(\phi_\alpha)\sin(\phi_\beta) \right\rangle$$

$$\left\langle \cos(\phi_\alpha + \phi_\beta) \right\rangle = \left\langle \cos(\phi_\alpha)\cos(\phi_\beta) \right\rangle - \left\langle \sin(\phi_\alpha)\sin(\phi_\beta) \right\rangle$$

we obtain

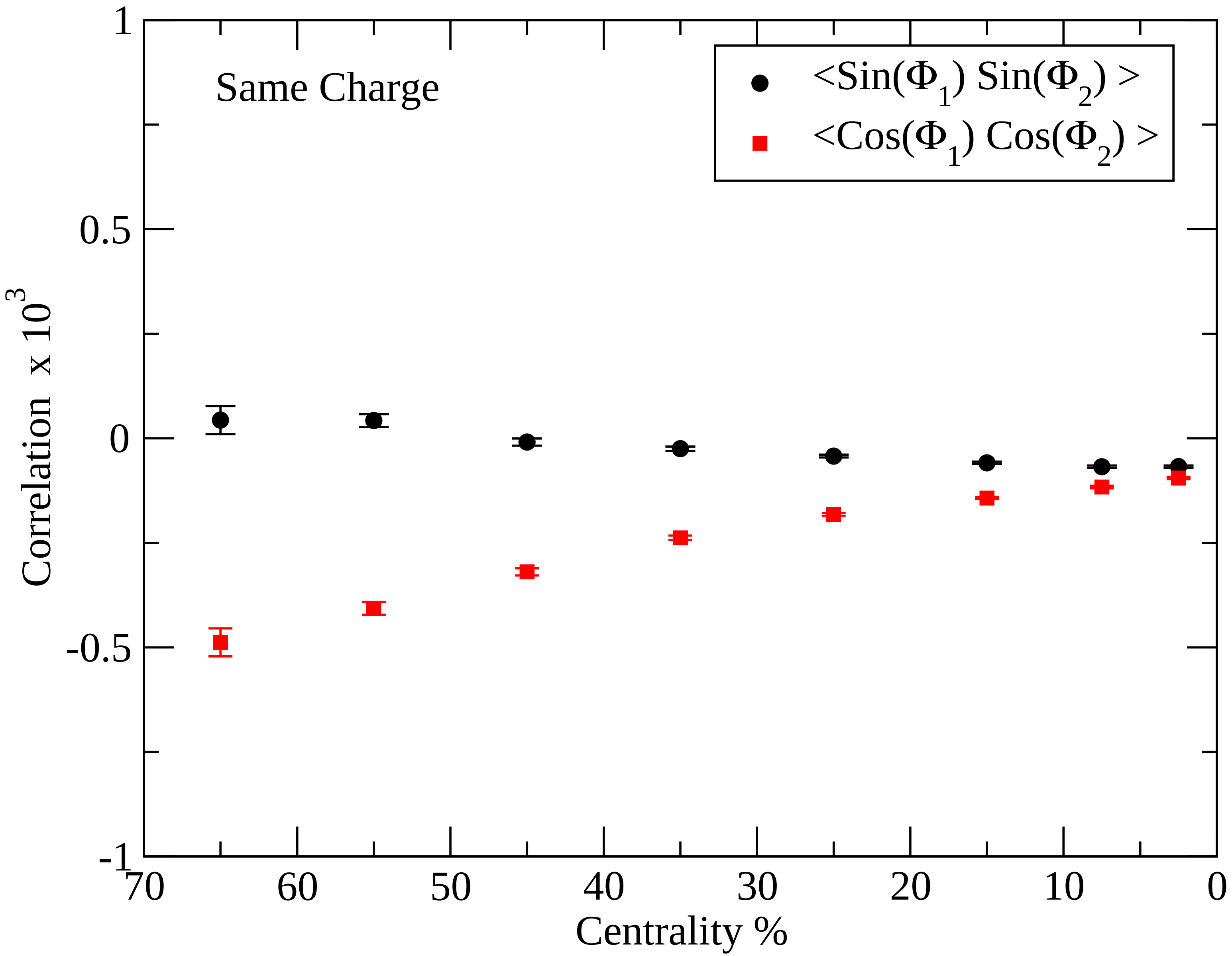
$$\left\langle \sin(\phi_\alpha)\sin(\phi_\beta) \right\rangle_{same} \simeq 0$$

$$\left\langle \cos(\phi_\alpha)\cos(\phi_\beta) \right\rangle_{same} < 0$$

and

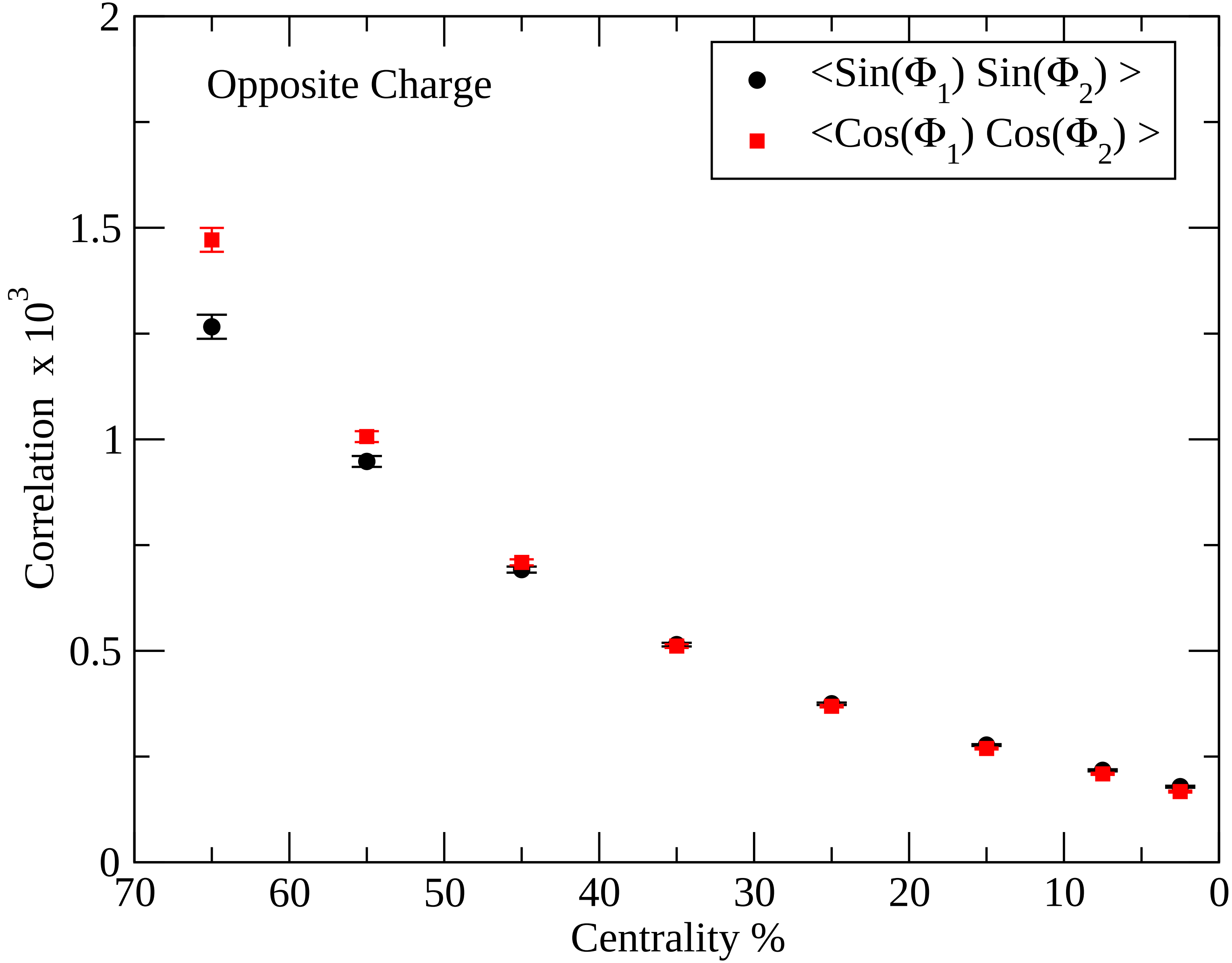
$$\left\langle \sin(\phi_\alpha)\sin(\phi_\beta) \right\rangle_{opposite} \simeq \left\langle \cos(\phi_\alpha)\cos(\phi_\beta) \right\rangle_{opposite} > 0$$

Same sign



Same Charge
<Sin(Φ1) Sin(Φ2) >
<Cos(Φ1) Cos(Φ2) >
Correlation x 10^3
Centrality %
1
0.5
0
-0.5
-1
70
60
50
40
30
20
10
0

Opposite sign



where is the parity?

$$\left\langle \sin(\phi_\alpha)\sin(\phi_\beta)\right\rangle_{same} \equiv P + B_{out}$$

$$\left\langle \sin(\phi_\alpha)\sin(\phi_\beta)\right\rangle_{same} \simeq 0$$

in consequence:

$$\boxed{\mathbf{P \simeq -B_{out}}}$$

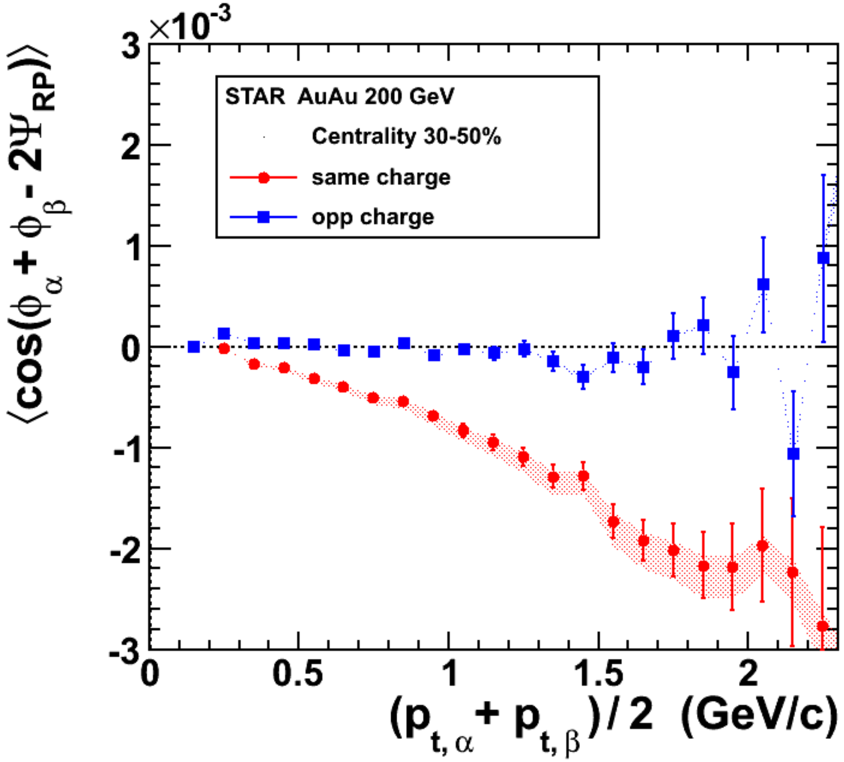
This is an unexpected relation ...

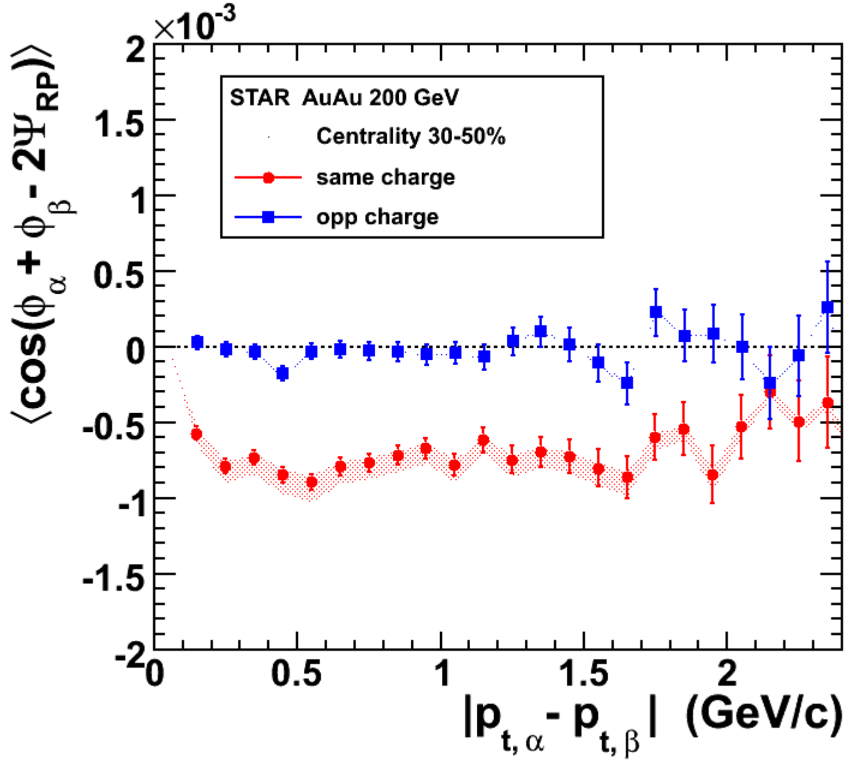
maybe it is lucky coincidence?

in order to answer that question we need differential (p_t, η) $\langle \cos(\boldsymbol{\phi_\alpha + \phi_\beta})\rangle$ and $\langle \cos(\boldsymbol{\phi_\alpha - \phi_\beta})\rangle$

p_t distribution

STAR data





$\langle\cos(\phi_\alpha + \phi_\beta)\rangle \propto p_{t,\alpha} + p_{t,\beta}$ and very weak dependence on $|p_{t,\alpha} - p_{t,\beta}|$

We will show that the true signal is located at low p_t

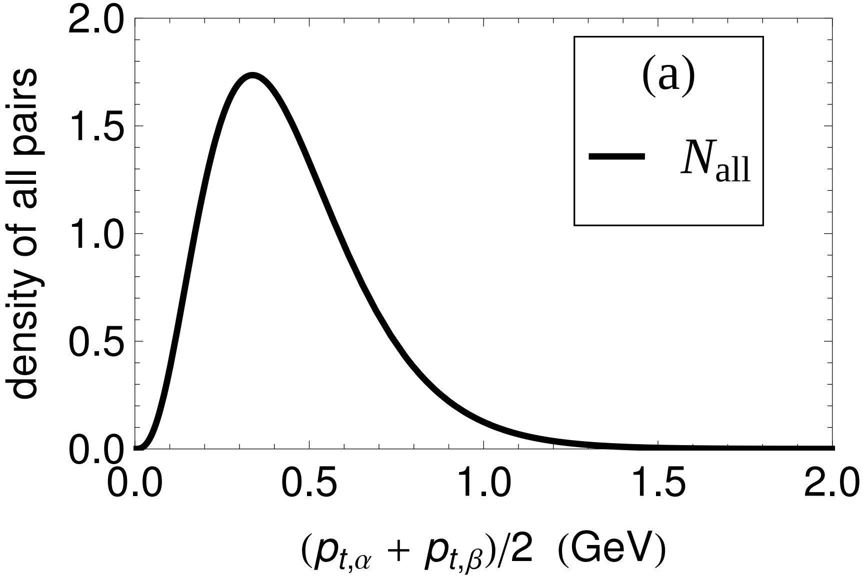
Definition

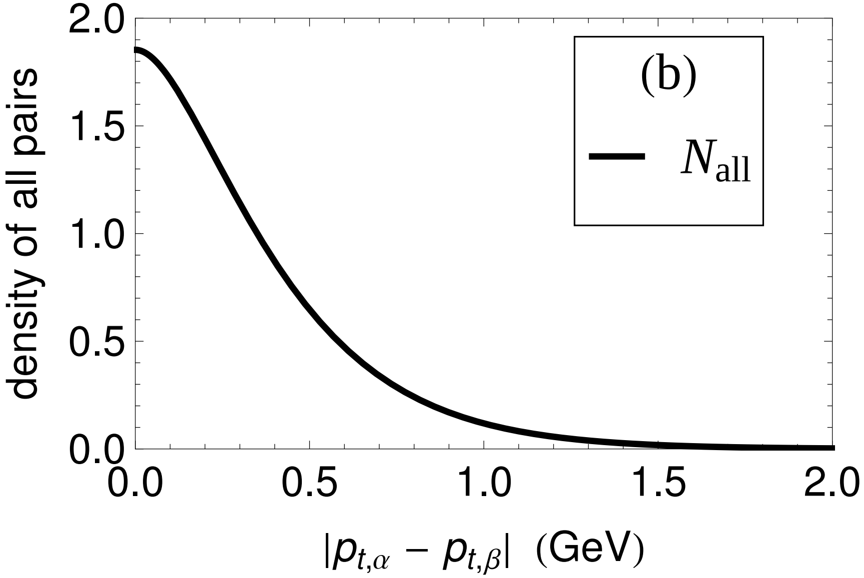
$$\left\langle \cos(\phi_\alpha + \phi_\beta) \right\rangle = \frac{\text{No. of correlated pairs}\left[\,\cos(\phi_\alpha + \phi_\beta)\right]}{\text{No. of all pairs}} \sim \frac{1}{1000}$$

We can calculate the (differential) number of all pairs

$$\int \exp\left(\frac{-p_{t,\alpha}}{T}\right) \exp\left(\frac{-p_{t,\beta}}{T}\right) d^2p_{t,\alpha} d^2p_{t,\beta}\bigg|_{\substack{\text{fixed } p_{t,\alpha}+p_{t,\beta} \text{ or} \\ \text{fixed } \left|p_{t,\alpha}-p_{t,\beta}\right|}}$$

The number of all pairs vs $(p_{t,\alpha} + p_{t,\beta})$ and $\left|p_{t,\alpha} - p_{t,\beta}\right|$



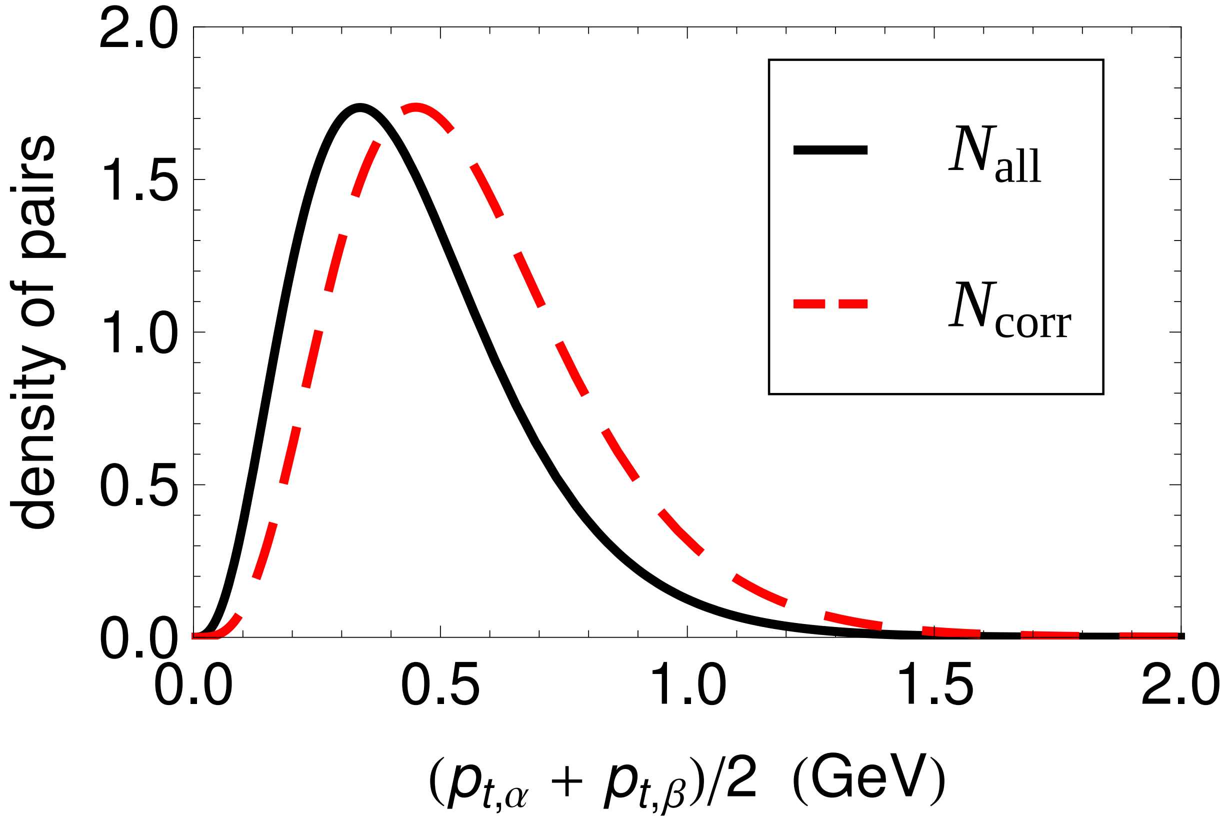


From that we can obtain p_t dependence of the number of correlated pairs:

– $\left|p_{t,\alpha} - p_{t,\beta}\right|$ distribution is as above (right plot)

– and multiply the left plot by $(p_{t,\alpha} + p_{t,\beta})$ ...

... we obtain [all pairs (black), correlated pairs (red)]



The observed signal is NOT inconsistent with the Chiral Magnetic Effect

v_2 and Coulomb effect

$$\left\langle \sin(\phi_\alpha)\sin(\phi_\beta)\right\rangle_{same} \equiv P + B_{out}$$

$$\left\langle \cos(\phi_\alpha)\cos(\phi_\beta)\right\rangle_{same} \equiv B_{in}$$

STAR assumption: $B_{in} \simeq B_{out}$ so that $|B_{in} - B_{out}| << P$, then

$$\left\langle \cos(\phi_\alpha + \phi_\beta)\right\rangle = \left\langle \cos(\phi_\alpha)\cos(\phi_\beta)\right\rangle - \left\langle \sin(\phi_\alpha)\sin(\phi_\beta)\right\rangle \approx -P$$

However for all 2-particle correlations that DO NOT depend on the reaction plane

$$p_2(\phi_1, \phi_2) = p_1(\phi_1)p_1(\phi_2)\left[1 + C\left(\phi_1 - \phi_2\right)\right]$$

we obtain

$$\boxed{B_{in} - B_{out} \propto v_2 \quad \Rightarrow \quad \left\langle \cos(\phi_\alpha + \phi_\beta)\right\rangle \propto v_2}$$

This is also true for correlations depending on $\left|\vec{k}_1 - \vec{k}_2\right|$ or $\left|\vec{k}_1 + \vec{k}_2\right|$

Indeed: $\left|\vec{k}_1 \pm \vec{k}_2\right|^2 \sim \vec{k}_1 \cdot \vec{k}_2 \sim \cos\left(\phi_1 - \phi_2\right)$

As an example we calculated the Coulomb effect (Gamow factor):

$$\left\langle \cos(\phi_\alpha + \phi_\beta) \right\rangle_{same} \approx -0.5 \cdot 10^{-3}$$

$$\left\langle \cos(\phi_\alpha - \phi_\beta) \right\rangle_{same} \approx -2.0 \cdot 10^{-3}$$

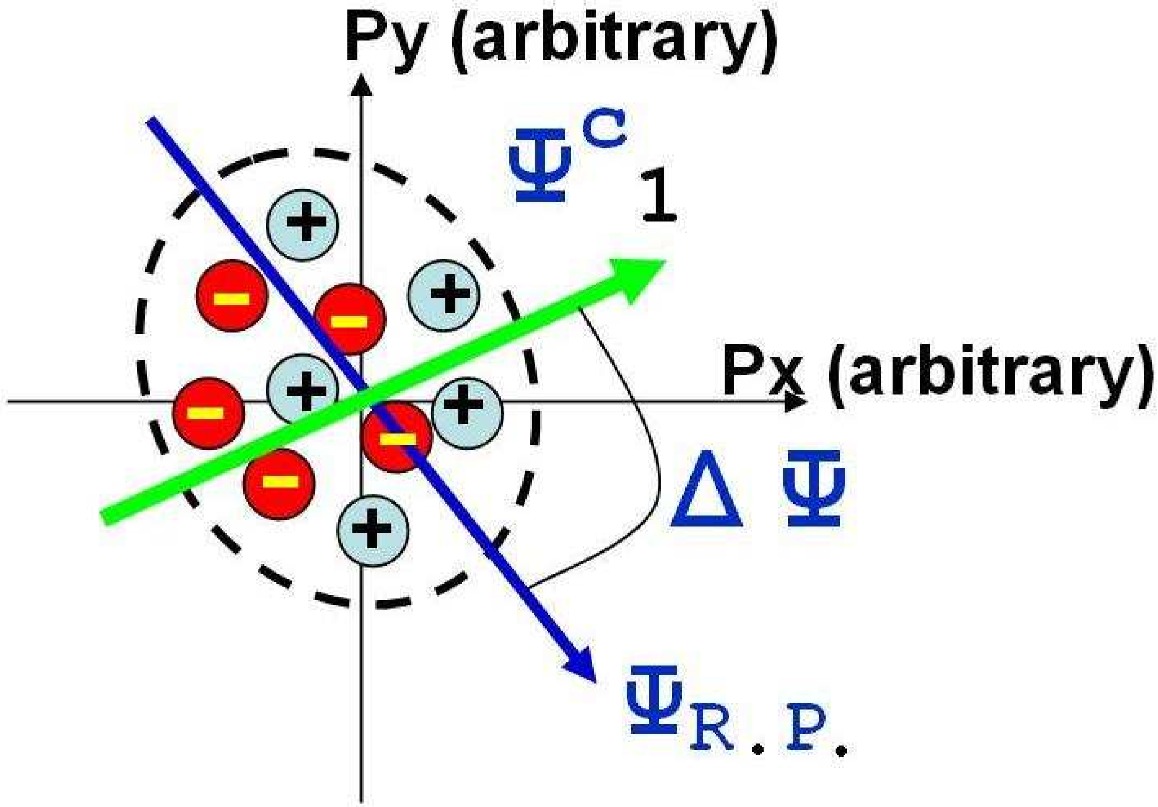
The Gamow factor is known to overestimate the effect.

Work in progress!

It is clear that we have to study all sources of correlations, not only those explicitly dependent on the reaction plane orientation

Dipole analysis

In each event we can measure size and orientation Ψ_1^c of the dipole



We can also determine orientation of the particle reaction plane Ψ_2 and study the relation between Ψ_1^c and Ψ_2

well known Q_2 analysis for elliptic flow:

$$Q_2 \cos\left(2\Psi_2\right) = \sum_i \cos(2\phi_i)$$

$$Q_2 \sin\left(2\Psi_2\right) = \sum_i \sin(2\phi_i)$$

new Q_1^c dipole analysis:

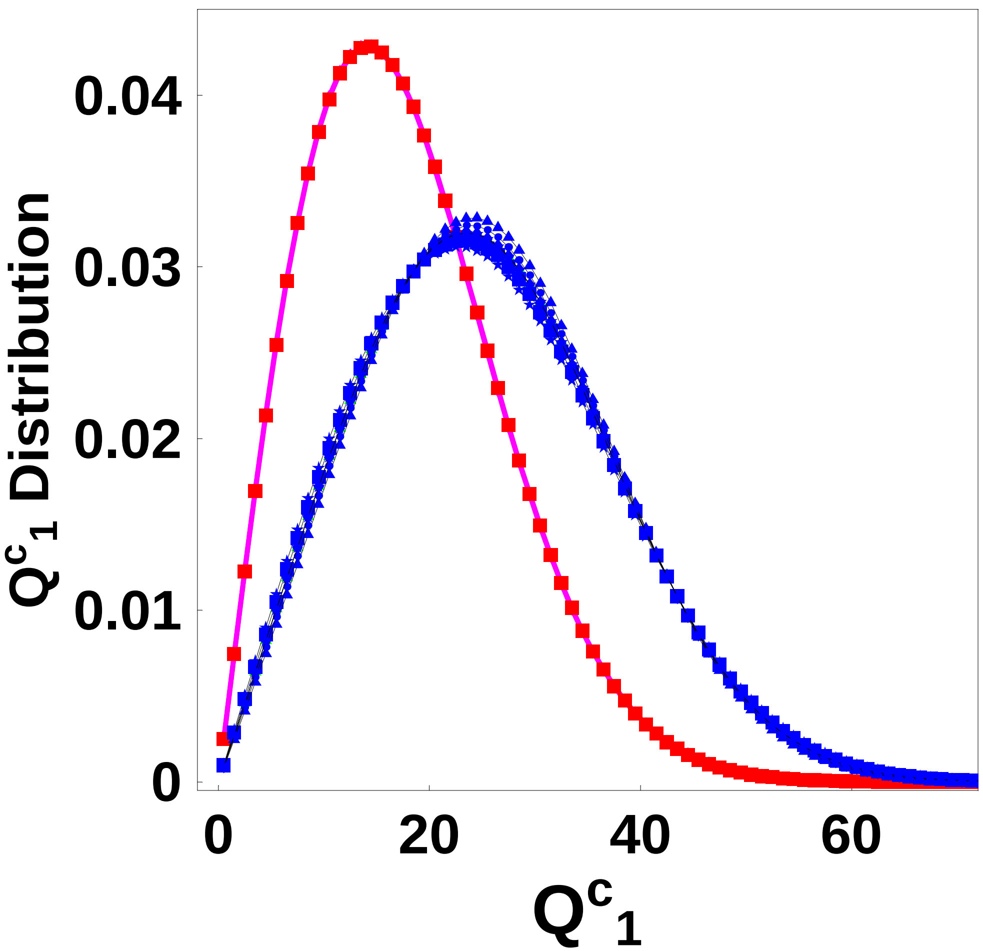
$$Q_1^c \cos\left(\Psi_1^c\right) = \sum_i q_i \cos(\phi_i)$$

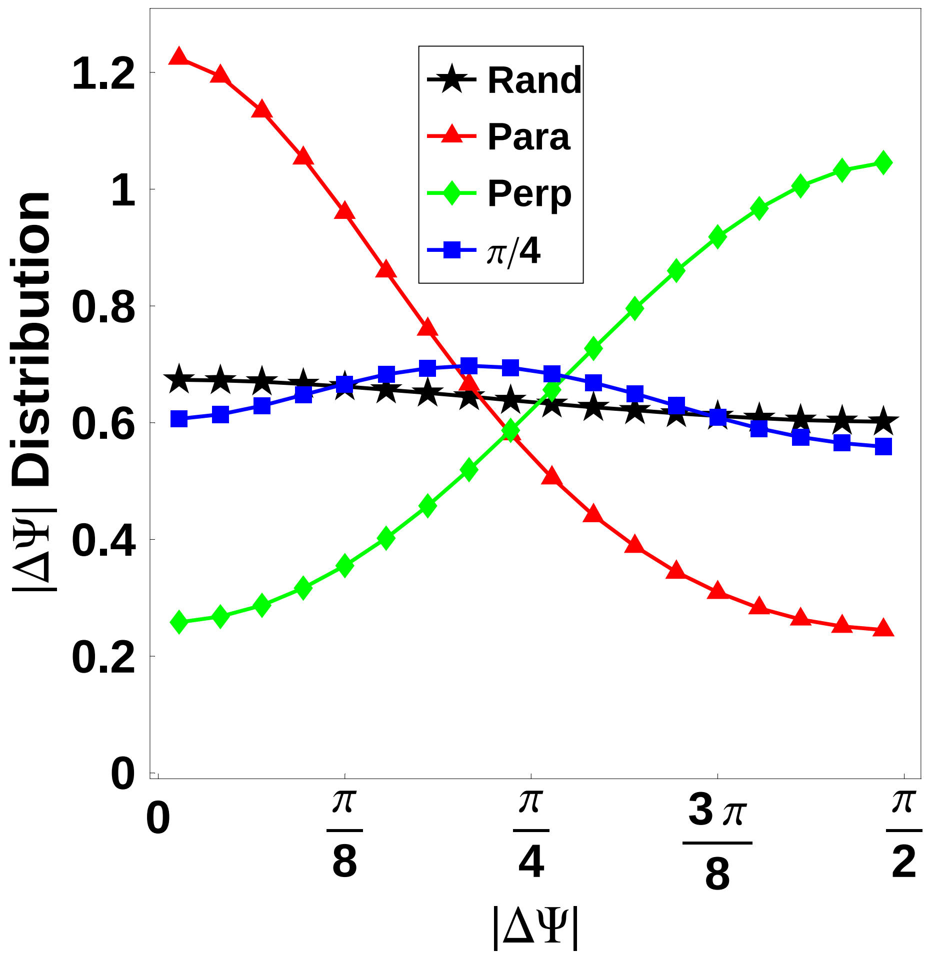
$$Q_1^c \sin\left(\Psi_1^c\right) = \sum_i q_i \sin(\phi_i)$$

In each event: (Q_2, Ψ_2) and $\left(Q_1^c, \Psi_1^c\right) \quad \Rightarrow \quad \boxed{\left\langle \cos\left(2\Psi_1^c - 2\Psi_2\right)\right\rangle}$

Monte Carlo: $f \propto 1 + 2v_2 \cos(2\phi - 2\Psi_{R.P.}) + 2q\chi d_1 \cos(\phi - \Psi_{C.S.})$

$200+$, $200-$, $v_2 = 0.1$, $d_1 = 0.05$, $\chi = \pm 1$





Good discriminating power, may clarify the situation

Conclusions

- for same sign STAR sees large correlations in-plane and very small correlations out-of-plane

- parity signal must almost exactly cancel out-of-plane background, maybe this is a lucky coincidence?

- we need differential $\langle \cos(\phi_\alpha - \phi_\beta) \rangle$ (p_t, η) to answer that question

- signal is dominated by $p_t < 1$ GeV and this is not inconsistent with the Chiral Magnetic Effect

- all two-particle correlations that do not depend on the reaction plane orientation contribute to the signal (v_2)

- as an example we studied Coulomb effect and found it surprisingly large (work still in progress)

- we proposed direct dipole analysis that may help to clarify the situation